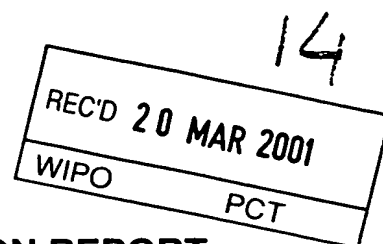


INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)



Applicant's or agent's file reference FB9248/E14432WO-H/JC		See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)
FOR FURTHER ACTION		
International application No. PCT/US99/26050	International filing date (day/month/year) 04/11/1999	Priority date (day/month/year) 06/11/1998
International Patent Classification (IPC) or national classification and IPC F01N3/28		
Applicant CERYX Incorporated et al.		

1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.


2. This REPORT consists of a total of 5 sheets, including this cover sheet.

- ☐ This report is also accompanied by ANNEXES, i.e. sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

These annexes consist of a total of sheets.

3. This report contains indications relating to the following items:

- I ☒ Basis of the report
- II ☐ Priority
- III ☒ Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
- IV ☐ Lack of unity of invention
- V ☐ Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement
- VI ☐ Certain documents cited
- VII ☒ Certain defects in the international application
- VIII ☐ Certain observations on the international application

Date of submission of the demand 06/06/2000	Date of completion of this report 16.03.2001
Name and mailing address of the international preliminary examining authority:  European Patent Office D-80298 Munich Tel. +49 89 2399 - 0 Tx: 523656 epmu d Fax: +49 89 2399 - 4465	Authorized officer Kolland, U Telephone No. +49 89 2399 8166



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**INTERNATIONAL PRELIMINARY
EXAMINATION REPORT**

International application No. PCT/US99/26050

I. Basis of the report

1. This report has been drawn on the basis of *(substitute sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to the report since they do not contain amendments (Rules 70.16 and 70.17).):*

Description, pages:

1-14 as originally filed

Claims, No.:

1-54 as originally filed

Drawings, sheets:

1/4-4/4 as originally filed

2. With regard to the **language**, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.

These elements were available or furnished to this Authority in the following language: , which is:

- ☐ the language of a translation furnished for the purposes of the international search (under Rule 23.1(b)).
- ☐ the language of publication of the international application (under Rule 48.3(b)).
- ☐ the language of a translation furnished for the purposes of international preliminary examination (under Rule 55.2 and/or 55.3).

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international preliminary examination was carried out on the basis of the sequence listing:

- ☐ contained in the international application in written form.
- ☐ filed together with the international application in computer readable form.
- ☐ furnished subsequently to this Authority in written form.
- ☐ furnished subsequently to this Authority in computer readable form.
- ☐ The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
- ☐ The statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished.

4. The amendments have resulted in the cancellation of:

- ☐ the description, pages:
- ☐ the claims, Nos.:

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**INTERNATIONAL PRELIMINARY
EXAMINATION REPORT**

International application No. PCT/US99/26050

☐ the drawings, sheets:

5. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed (Rule 70.2(c)):

(Any replacement sheet containing such amendments must be referred to under item 1 and annexed to this report.)

6. Additional observations, if necessary:

III. Non-establishment of opinion with regard to novelty, inventive step and industrial applicability

1. The questions whether the claimed invention appears to be novel, to involve an inventive step (to be non-obvious), or to be industrially applicable have not been examined in respect of:

☒ the entire international application.

☐ claims Nos. .

because:

☐ the said international application, or the said claims Nos. relate to the following subject matter which does not require an international preliminary examination (*specify*):

☒ the description, claims or drawings (*indicate particular elements below*) or said claims Nos. 1-54 are so unclear that no meaningful opinion could be formed (*specify*):
see separate sheet

☐ the claims, or said claims Nos. are so inadequately supported by the description that no meaningful opinion could be formed.

☐ no international search report has been established for the said claims Nos. .

2. A meaningful international preliminary examination report cannot be carried out due to the failure of the nucleotide and/or amino acid sequence listing to comply with the standard provided for in Annex C of the Administrative Instructions:

☐ the written form has not been furnished or does not comply with the standard.

☐ the computer readable form has not been furnished or does not comply with the standard.

VII. Certain defects in the international application

The following defects in the form or contents of the international application have been noted:
see separate sheet

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Re Item III

Non-establishment of opinion with regard to novelty, inventive step and industrial applicability

1. Claims 1, 21, 34, 36, 46 and 53 have been drafted as separate independent claims containing different subject-matter. Multiple claims with differing subject matter disguise which features are important for the invention and are therefore unclear (Article 6 PCT).

Since the independent claims 1, 21, 34, 36, 46 and 53 are unclear (Article 6 PCT), no meaningful reasoned statement under point V. can be established for these claims.

2. As well as being unclear, the claims appear to lack unity of invention. The application comprises three separate groups of inventions whereby two groups are not so linked as to form a single general inventive concept. These two groups of invention are:

- independent claims 1 and 36 describe an apparatus (and method) comprising a particulate filter for collecting and oxidizing particulate matter.
- independent claims 21 and 46 describe an apparatus (and method) comprising a lean-NO_x catalyst for reducing nitrogen oxides in the fluid stream.

The first group doesn't mention a NO_x catalysing function. The second group doesn't mention a particulate filter.

While the features of each group could be used in combination with the subject-matter of the other group (see claims 34 and 53), it is not limited to such use, and thus, each of the aforementioned groups represents a separate idea.

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**INTERNATIONAL PRELIMINARY
EXAMINATION REPORT - SEPARATE SHEET**

International application No. PCT/US99/26050

Re Item VII

Certain defects in the international application

1. Contrary to the requirements of Rule 5.1(a)(ii) PCT, the relevant background art disclosed in document US-A-5 335 492 (=D1) is not mentioned in the description, nor is this document identified therein.
2. The features of the claims are not provided with reference signs placed in parentheses (Rule 6.2(b) PCT).

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M.H

PATENT COOPERATION TREATY

PCT

INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference WDF-69436	FOR FURTHER ACTION see Notification of Transmittal of International Search Report (Form PCT/ISA/220) as well as, where applicable, item 5 below.	
International application No. PCT/US 99/ 26050	International filing date (day/month/year) 04/11/1999	(Earliest) Priority Date (day/month/year) 06/11/1998
Applicant CERYX Incorporated et al.		

This International Search Report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This International Search Report consists of a total of 3 sheets.

☒ It is also accompanied by a copy of each prior art document cited in this report.

1. Basis of the report

- a. With regard to the language, the international search was carried out on the basis of the international application in the language in which it was filed, unless otherwise indicated under this item.

☐ the international search was carried out on the basis of a translation of the international application furnished to this Authority (Rule 23.1(b)).

- b. With regard to any nucleotide and/or amino acid sequence disclosed in the international application, the international search was carried out on the basis of the sequence listing:

☐ contained in the international application in written form.

☐ filed together with the international application in computer readable form.

☐ furnished subsequently to this Authority in written form.

☐ furnished subsequently to this Authority in computer readable form.

☐ the statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.

☐ the statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished

2. ☐ Certain claims were found unsearchable (See Box I).

3. ☐ Unity of invention is lacking (see Box II).

4. With regard to the title,

☒ the text is approved as submitted by the applicant.

☐ the text has been established by this Authority to read as follows:

5. With regard to the abstract,

☒ the text is approved as submitted by the applicant.

☐ the text has been established, according to Rule 38.2(b), by this Authority as it appears in Box III. The applicant may, within one month from the date of mailing of this international search report, submit comments to this Authority.

6. The figure of the drawings to be published with the abstract is Figure No.

☒ as suggested by the applicant.

☐ because the applicant failed to suggest a figure.

☐ because this figure better characterizes the invention.

1
☐ None of the figures.

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PATENT COOPERATION TREATY

PCT

NOTIFICATION OF ELECTION

(PCT Rule 61.2)

From the INTERNATIONAL BUREAU

To:

Assistant Commissioner for Patents
United States Patent and Trademark
Office
Box PCT
Washington, D.C. 20231
ETATS-UNIS D'AMERIQUE

in its capacity as elected Office

Date of mailing (day/month/year) 21 July 2000 (21.07.00)	
International application No. PCT/US99/26050	Applicant's or agent's file reference WDF-69436
International filing date (day/month/year) 04 November 1999 (04.11.99)	Priority date (day/month/year) 06 November 1998 (06.11.98)
Applicant PAGE, Dorriah, L. et al	

1. The designated Office is hereby notified of its election made:

☒ in the demand filed with the International Preliminary Examining Authority on:

06 June 2000 (06.06.00)

☐ in a notice effecting later election filed with the International Bureau on:

2. The election ☒ was
☐ was not

made before the expiration of 19 months from the priority date or, where Rule 32 applies, within the time limit under Rule 32.2(b).

The International Bureau of WIPO 34, chemin des Colombettes 1211 Geneva 20, Switzerland Facsimile No.: (41-22) 740.14.35	Authorized officer Juan Cruz Telephone No.: (41-22) 338.83.38
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PATENT COOPERATION TREATY

From the
INTERNATIONAL PRELIMINARY EXAMINING AUTHORITY

RECEIVED
PCT
03 JUL 2000
FILE NUMBER

To:
HOWDEN, C.A..
FORRESTER & BOEHMERT
Franz-Joseph-Strasse 38
D-80801 München
ALLEMAGNE

FORRESTER & BOEHMERT
NOTIFICATION OF RECEIPT
OF DEMAND BY COMPETENT INTERNATIONAL
PRELIMINARY EXAMINING AUTHORITY
Eng./Roc.: 30. JUN 2000
Post. []
[]

(PCT Rules 59.3(e) and 61.1(b), first sentence
and Administrative Instructions, Section 601(a))

Date of mailing
(day/month/year) 29.06.00

Applicant's or agent's file reference FB9248/E14432WO-H/JC		IMPORTANT NOTIFICATION	
International application No. PCT/US 99/ 26050	International filing date (day/month/year) 04/11/1999	Priority date (day/month/year) 06/11/1998	
Applicant CERYX Incorporated et.al.			

1. The applicant is hereby notified that this International Preliminary Examining Authority considers the following date as the date of receipt of the demand for international preliminary examination of the international application:

06/06/2000

2. This date of receipt is:

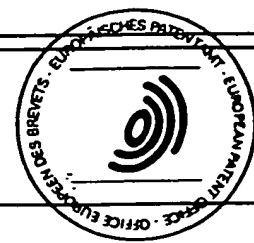
- ☒ the actual date of receipt of the demand by this Authority (Rule 61.1(b)).
- ☐ the actual date of receipt of the demand on behalf of this Authority (Rule 59.3(e)).
- ☐ the date on which this Authority has, in response to the invitation to correct defects in the demand (Form PCT/IPEA/404), received the required corrections.

3. ☐ **ATTENTION:** That date of receipt is **AFTER** the expiration of 19 months from the priority date. Consequently, the election(s) made in the demand does (do) not have the effect of postponing the entry into the national phase until 30 months from the priority date (or later in some Offices) (Article 39(1)). Therefore, the acts for entry into the national phase must be performed within 20 months from the priority date (or later in some Offices) (Article 22). For details, see the *PCT Applicant's Guide*, Volume II.

☐ (If applicable) This notification confirms the information given by telephone, facsimile transmission or in person on:

4. Only where paragraph 3 applies, a copy of this notification has been sent to the International Bureau.

Name and mailing address of the IPEA/ European Patent Office D-80298 Munich Tel. (+ 49-89) 2399-0, Tx: 523656 epmu d Fax: (+ 49-89) 2399-4465	Authorized officer KEMLE S Y G Tel. (+ 49-89) 2399-8588
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PATENT COOPERATIVE TREATY

From the
INTERNATIONAL PRELIMINARY EXAMINING AUTHORITY

PCT

To:

HOWDEN, C.A..
FORRESTER & BOEHMERT
Franz-Joseph-Strasse
D-80801 München
ALLEMAGNE

FORRESTER & BOEHMERT	
BB: 19.03.2001	
Frist / Term: 06.05.01 (30 wks)	
Ext. / Decl. w.: 06.06.01 (30 wks)	

NOTIFICATION OF TRANSMITTAL OF
THE INTERNATIONAL PRELIMINARY
EXAMINATION REPORT
(PCT Rule 71.1)

Date of mailing
(day/month/year) 16.03.2001

Applicant's or agent's file reference
FB9248/E14432WO-H/JC

IMPORTANT NOTIFICATION

International application No.
PCT/US99/26050

International filing date (day/month/year)
04/11/1999

Priority date (day/month/year)
06/11/1998

Applicant
CERYX Incorporated et al.

20 MAR 2001
FORRESTER & BOEHMERT

1. The applicant is hereby notified that this International Preliminary Examining Authority transmits herewith the international preliminary examination report and its annexes, if any, established on the international application.
2. A copy of the report and its annexes, if any, is being transmitted to the International Bureau for communication to all the elected Offices.
3. Where required by any of the elected Offices, the International Bureau will prepare an English translation of the report (but not of any annexes) and will transmit such translation to those Offices.

4. REMINDER

The applicant must enter the national phase before each elected Office by performing certain acts (filing translations and paying national fees) within 30 months from the priority date (or later in some Offices) (Article 39(1)) (see also the reminder sent by the International Bureau with Form PCT/IB/301).

Where a translation of the international application must be furnished to an elected Office, that translation must contain a translation of any annexes to the international preliminary examination report. It is the applicant's responsibility to prepare and furnish such translation directly to each elected Office concerned.

For further details on the applicable time limits and requirements of the elected Offices, see Volume II of the PCT Applicant's Guide.

WU
OC

Name and mailing address of the IPEA/

European Patent Office
D-80298 Munich
Tel. +49 89 2399 - 0 Tx: 523656 epmu d
Fax: +49 89 2399 - 4465

Authorized officer

Lindquist, P

Tel. +49 89 2399-2324



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PATENT COOPERATION TREATY

PCT

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference FB9248/E14432WO-H/JC	FOR FURTHER ACTION See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)	
International application No. PCT/US99/26050	International filing date (day/month/year) 04/11/1999	Priority date (day/month/year) 06/11/1998
International Patent Classification (IPC) or national classification and IPC F01N3/28		
Applicant CERYX Incorporated et al.		

1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.



2. This REPORT consists of a total of 5 sheets, including this cover sheet.

- ☐ This report is also accompanied by ANNEXES, i.e. sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

These annexes consist of a total of sheets.

3. This report contains indications relating to the following items:

- I ☒ Basis of the report
- II ☐ Priority
- III ☒ Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
- IV ☐ Lack of unity of invention
- V ☐ Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement
- VI ☐ Certain documents cited
- VII ☒ Certain defects in the international application
- VIII ☐ Certain observations on the international application

Date of submission of the demand 06/06/2000	Date of completion of this report 16.03.2001
Name and mailing address of the international preliminary examining authority:  European Patent Office D-80298 Munich Tel. +49 89 2399 - 0 Tx: 523656 epmu d Fax: +49 89 2399 - 4465	Authorized officer Kolland, U Telephone No. +49 89 2399 8166 

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**INTERNATIONAL PRELIMINARY
EXAMINATION REPORT**

International application No. PCT/US99/26050

I. Basis of the report

1. This report has been drawn on the basis of *(substitute sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to the report since they do not contain amendments (Rules 70.16 and 70.17).)*

Description, pages:

1-14 as originally filed

Claims, No.:

1-54 as originally filed

Drawings, sheets:

1/4-4/4 as originally filed

2. With regard to the **language**, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.

These elements were available or furnished to this Authority in the following language: , which is:

- ☐ the language of a translation furnished for the purposes of the international search (under Rule 23.1(b)).
- ☐ the language of publication of the international application (under Rule 48.3(b)).
- ☐ the language of a translation furnished for the purposes of international preliminary examination (under Rule 55.2 and/or 55.3).

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international preliminary examination was carried out on the basis of the sequence listing:

- ☐ contained in the international application in written form.
- ☐ filed together with the international application in computer readable form.
- ☐ furnished subsequently to this Authority in written form.
- ☐ furnished subsequently to this Authority in computer readable form.
- ☐ The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
- ☐ The statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished.

4. The amendments have resulted in the cancellation of:

- ☐ the description, pages:
- ☐ the claims, Nos.:

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**INTERNATIONAL PRELIMINARY
EXAMINATION REPORT**

International application No. PCT/US99/26050

☐ the drawings, sheets:

5. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed (Rule 70.2(c)):

(Any replacement sheet containing such amendments must be referred to under item 1 and annexed to this report.)

6. Additional observations, if necessary:

III. Non-establishment of opinion with regard to novelty, inventive step and industrial applicability

1. The questions whether the claimed invention appears to be novel, to involve an inventive step (to be non-obvious), or to be industrially applicable have not been examined in respect of:

☒ the entire international application.

☐ claims Nos. .

because:

☐ the said international application, or the said claims Nos. relate to the following subject matter which does not require an international preliminary examination (*specify*):

☒ the description, claims or drawings (*indicate particular elements below*) or said claims Nos. 1-54 are so unclear that no meaningful opinion could be formed (*specify*):
see separate sheet

☐ the claims, or said claims Nos. are so inadequately supported by the description that no meaningful opinion could be formed.

☐ no international search report has been established for the said claims Nos. .

2. A meaningful international preliminary examination report cannot be carried out due to the failure of the nucleotide and/or amino acid sequence listing to comply with the standard provided for in Annex C of the Administrative Instructions:

☐ the written form has not been furnished or does not comply with the standard.

☐ the computer readable form has not been furnished or does not comply with the standard.

VII. Certain defects in the international application

The following defects in the form or contents of the international application have been noted:
see separate sheet

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Re Item III

Non-establishment of opinion with regard to novelty, inventive step and industrial applicability

1. Claims 1, 21, 34, 36, 46 and 53 have been drafted as separate independent claims containing different subject-matter. Multiple claims with differing subject matter disguise which features are important for the invention and are therefore unclear (Article 6 PCT).

Since the independent claims 1, 21, 34, 36, 46 and 53 are unclear (Article 6 PCT), no meaningful reasoned statement under point V. can be established for these claims.

2. As well as being unclear, the claims appear to lack unity of invention. The application comprises three separate groups of inventions whereby two groups are not so linked as to form a single general inventive concept. These two groups of invention are:

- independent claims 1 and 36 describe an apparatus (and method) comprising a particulate filter for collecting and oxidizing particulate matter.
- independent claims 21 and 46 describe an apparatus (and method) comprising a lean-NO_x catalyst for reducing nitrogen oxides in the fluid stream.

The first group doesn't mention a NO_x catalysing function. The second group doesn't mention a particulate filter.

While the features of each group could be used in combination with the subject-matter of the other group (see claims 34 and 53), it is not limited to such use, and thus, each of the aforementioned groups represents a separate idea.

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**INTERNATIONAL PRELIMINARY
EXAMINATION REPORT - SEPARATE SHEET**

International application No. PCT/US99/26050

Re Item VII

Certain defects in the international application

1. Contrary to the requirements of Rule 5.1(a)(ii) PCT, the relevant background art disclosed in document US-A-5 335 492 (=D1) is not mentioned in the description, nor is this document identified therein.

2. The features of the claims are not provided with reference signs placed in parentheses (Rule 6.2(b) PCT).

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PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau



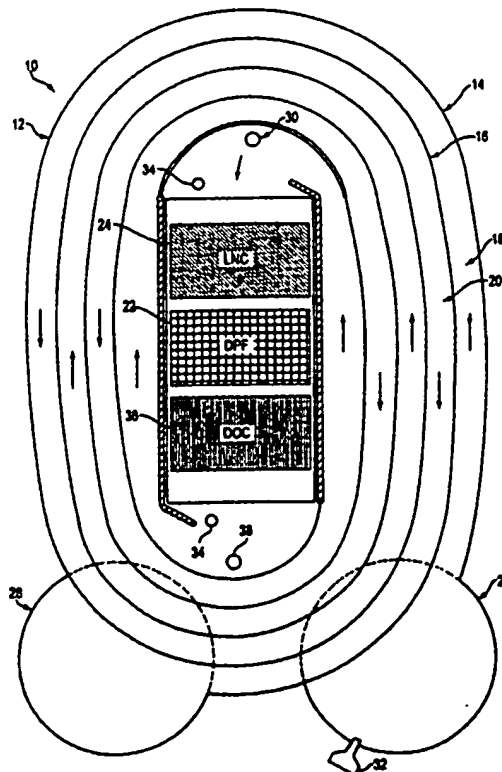
INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 7 : F01N 3/28, 3/20, 3/035, B01D 53/94		(11) International Publication Number: WO 00/28196
A1		(43) International Publication Date: 18 May 2000 (18.05.00)
(21) International Application Number: PCT/US99/26050		(81) Designated States: AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZA, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).
(22) International Filing Date: 4 November 1999 (04.11.99)		
(30) Priority Data: 60/107,482 6 November 1998 (06.11.98) US		
(71) Applicant (for all designated States except US): CERYX INCORPORATED [US/US]; 1343 East Main Street, Santa Paula, CA 93060 (US).		
(72) Inventors; and (75) Inventors/Applicants (for US only): PAGE, Dorriah, L. [US/US]; 1151 Corte Barroso, Camarillo, CA 93010 (US). EDGAR, Bradley, L. [US/US]; 293 Whitmore Street, No. 5, Oakland, CA 94611 (US). MACDONALD, Robert, J. [US/US]; 6200 Vista Del Mar, No. 207, Playa Del Rey, CA 90293 (US).		
(74) Agent: BRUEGGEMANN, James, R.; Sheppard Mullin Richter & Hampton LLP, 48th floor, 333 South Hope Street, Los Angeles, CA 90071 (US).		Published With international search report.

(54) Title: INTEGRATED APPARATUS FOR REMOVING POLLUTANTS FROM A FLUID STREAM IN A LEAN-BURN ENVIRONMENT WITH HEAT RECOVERY

(57) Abstract

An apparatus and method to treat fluid streams, and in particular emissions from lean-burn engines such as diesel engines, are disclosed, which use multiple catalysts chosen to remove hydrocarbons, carbon monoxide, particulate matter, and oxides of nitrogen. The apparatus and method also provide for heat exchange between the inlet and outlet exhaust streams to sustain the catalyzed reactions, by placing the catalysts in the temperature zones where their operation is enhanced, and they also allow for regeneration of a filter used to trap particulate matter in the streams.



FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	ES	Spain	LS	Lesotho	SI	Slovenia
AM	Armenia	FI	Finland	LT	Lithuania	SK	Slovakia
AT	Austria	FR	France	LU	Luxembourg	SN	Senegal
AU	Australia	GA	Gabon	LV	Latvia	SZ	Swaziland
AZ	Azerbaijan	GB	United Kingdom	MC	Monaco	TD	Chad
BA	Bosnia and Herzegovina	GE	Georgia	MD	Republic of Moldova	TC	Togo
BB	Barbados	GH	Ghana	MG	Madagascar	TJ	Tajikistan
BE	Belgium	GN	Guinea	MK	The former Yugoslav Republic of Macedonia	TM	Turkmenistan
BF	Burkina Faso	GR	Greece	ML	Mali	TR	Turkey
BG	Bulgaria	HU	Hungary	MN	Mongolia	TT	Trinidad and Tobago
BJ	Benin	IE	Ireland	MR	Mauritania	UA	Ukraine
BR	Brazil	IL	Israel	MW	Malawi	UG	Uganda
BY	Belarus	IS	Iceland	MX	Mexico	US	United States of America
CA	Canada	IT	Italy	NE	Niger	UZ	Uzbekistan
CF	Central African Republic	JP	Japan	NL	Netherlands	VN	Viet Nam
CG	Congo	KE	Kenya	NO	Norway	YU	Yugoslavia
CH	Switzerland	KG	Kyrgyzstan	NZ	New Zealand	ZW	Zimbabwe
CI	Côte d'Ivoire	KP	Democratic People's Republic of Korea	PL	Poland		
CM	Cameroon	KR	Republic of Korea	PT	Portugal		
CN	China	KZ	Kazakhstan	RO	Romania		
CU	Cuba	LC	Saint Lucia	RU	Russian Federation		
CZ	Czech Republic	LI	Liechtenstein	SD	Sudan		
DE	Germany	LK	Sri Lanka	SE	Sweden		
DK	Denmark	LR	Liberia	SG	Singapore		
EE	Estonia						

INTEGRATED APPARATUS FOR REMOVING POLLUTANTS FROM A FLUID
STREAM IN A LEAN-BURN ENVIRONMENT WITH HEAT RECOVERY

5 BACKGROUND OF THE INVENTION

This invention relates generally to apparatus for treating the exhaust streams of lean-burn engines and, more particularly, to apparatus of this kind that catalytically oxidize hydrocarbons, particulate matter, and carbon monoxide, and that
10 catalytically reduce nitrogen oxides.

Emissions components

Lean-burn engines, such as diesel engines, emit various gases, including
15 nitrogen oxides (NO_x), gaseous hydrocarbons (HC), carbon monoxide (CO), and sulfur dioxide, SO₂, and also emit combined solids and liquids called particulate matter (PM). This PM is composed of dry carbon (i.e., soot), inorganic oxides (primarily as sulfates) and liquids (such as condensed hydrocarbons). The sulfates, which are formed during combustion by the oxidation of sulfur present in the diesel fuel, react with the moisture
20 in the exhaust to form sulfuric acid, H₂SO₄. The liquids are a combination of unburned fuel and lubricating oils called the soluble organic fraction (SOF).

Treatment needs

25 Diesel emissions are more complex than those from gasoline engines, and their catalytic treatment is more complicated. Governmental efforts to reduce engine emissions are becoming stronger, with concerns over global warming, human health effects, and high fuel prices leading to renewed interest in lean-burn engines. Intense focus has been given, in particular, to the reduction of PM and NO_x in lean-burn
30 engines. Most approaches aimed at reducing one of these two pollutants have led to an increase in the other. This characteristic, known as the PM/NO_x trade-off, has

remained problematic to the diesel engine industry. Therefore, these engines continue to require exhaust aftertreatment to meet these tougher emissions standards.

Current Treatment

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Current oxidation catalysts used to reduce HC, CO and the soluble organic fraction of PM are typically washcoat-deposited on the channel walls of a cordierite- or another ceramic-based substrate. These catalysts are usually platinum- or palladium-based, and can be supported by alumina, zirconia, and vanadia with various promoter oxides such as rare earths. Current catalyst technology can reduce the soluble organic fraction of the PM as well as CO and HC, but cannot reduce NOx. Traditional automotive three-way catalysts cannot reduce NOx in excess air, such as is present in a lean-burn environment. A system solution is one way to achieve this simultaneous reduction of HC, CO, PM, and NOx.

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The oxidation of HC and CO over a catalyst in a lean-burn environment has not traditionally been difficult, provided the exhaust gases and catalyst are above the so-called "light-off" temperature. Oxidation catalysts are typically composed of platinum or palladium impregnated on a washcoat that is applied to a catalyst substrate. For NOx reduction, a catalyst that could decompose NOx to N₂ and O₂ would provide the ideal solution; however, such a catalyst has proven difficult to develop. Alternatively, a large number of catalyst formulations have been shown to promote NOx reduction in the presence of HC. Using these formulations, the NOx acts as an oxidizer to convert HC to carbon dioxide and water. In practice, the HC reducing agent comes either from unburned fuel leaving the engine cylinder, or from post-combustion injection of fuel into the cylinder, exhaust manifold, or exhaust duct upstream of any exhaust aftertreatment apparatus.

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While oxidation catalysts are effective in oxidizing the SOF component of the PM, they are not effective in oxidizing solid carbon. An alternative approach is to

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filter, or trap, the PM with a diesel particulate filter (DPF). However, DPFs have not been in widespread use, principally because the collected PM builds up on the filter, eventually leading to high back-pressure, which leads to reduced power and fuel economy. Further, excessive back-pressure from a blocked filter can damage the engine. A number of approaches have been proposed to burn off the PM, or to regenerate the DPF. These include, but are not limited to, the use of burners, catalytic fuel additives, and catalyzed DPFs.

There remains a need for an effective apparatus for reduction of all major pollutant types in a lean-burn environment, which is integrated and convenient, and which incorporates a NOx reduction function along with a DPF, and a means to regenerate the DPF. The present invention fulfills this need and provides further related advantages.

SUMMARY OF THE INVENTION

The present invention resides in an integrated apparatus for effectively and conveniently oxidizing and reducing pollutants in a variety of lean-burn environments. These environments include various types of engines, such as diesel internal combustion, dual-fuel (diesel and natural gas), dedicated spark-ignited lean-burn, and homogenous charge compression ignition. The apparatus preferably is positioned downstream of the turbocharger in the exhaust duct of a lean-burn engine. The apparatus allows for treatment for particulate matter (PM), hydrocarbon (HC), carbon monoxide (CO) and nitrogen oxides (NOx) in one integrated system, and allows for recovery of heat from these reactions for preheat of the incoming exhaust stream to raise the internal catalyst temperature.

The apparatus makes use of a catalyzed diesel particulate filter (DPF), and also can include a lean-NOx catalyst (LNC), and/or a diesel oxidation catalyst (DOC), integrated together within a novel heat exchanger design. The heat exchanger

is preferably in a spiral configuration, but can also be in other known configurations, such as shell-and-tube, plate-and-frame, rotating bed, or flow-switching.

The DPF provides catalytic treatment of HC, CO and PM. The DPF captures PM from the stream, and is regenerated to prevent pressure drop from collected PM on the filter becoming excessive. The DPF is preferably a wall flow particulate filter made of a ceramic material such as cordierite, silicon carbide, mullite, or a number of other high temperature porous ceramic substrates. Alternative configurations to the wall-flow filter geometry include small pore ceramic foams, sintered metal meshes, and ceramic fiber yarns. All provide large filtration areas with pore sizes small enough to provide a filtering function.

The DPF material also can be coated or impregnated with a catalytic material to lower the necessary temperature for regeneration. Catalytic materials include precious metals such as platinum or palladium, or non-precious metal compounds such as ceramic oxides (e.g., Mn-O).

The apparatus also can employ a LNC in the appropriate temperature regions of the heat exchanger for the reduction of oxides of nitrogen. The LNC reacts the NO_x with HC, that either is present in the entering stream, or alternatively is provided by a fuel injector, as discussed below. The LNC can be placed adjacent to the DPF, or elsewhere upstream of the DPF. Alternatively, the LNC can be deposited on the upstream surfaces of the DPF. The LNC preferably has a monolithic structure, but also can be comprised of ceramic or metal foam. Suitable active metals include platinum, iron, tin, or copper. Washcoats can be either alumina- or zeolite-based. Also, high-surface-area alumina can function as a LNC with the addition of precious or base metals.

The apparatus also can employ a DOC in the appropriate temperature regions of the heat exchanger for oxidation of stream constituents. DOCs can use

precious metals such as platinum, palladium, or gold, and they can be impregnated on alumina or zeolite washcoats.

5 The apparatus also can employ a fuel injector to inject HC into the stream at the inlet passage. This injected HC, when reacted over the LNC, DOC, or catalyzed DPF, can elevate the temperature at the DPF to improve the oxidation rate of the PM for regeneration. The apparatus also employs pressure, temperature and engine speed sensors, and also a controller to regulate the rate of HC injection to appropriate levels. Alternatively, an electric resistance heater can be used to heat the fluid stream in the
10 inlet passage, if necessary. Further, the HC injection can be incorporated into a burner system to allow flame-based heating of the catalyst if the catalyst is below its light-off temperature.

The apparatus enables a modern engine to achieve the increasingly
15 difficult standards for heavy-duty engines, without significant changes in fuel injection equipment, and without employing advanced exhaust gas recirculation. The compact size and excellent noise abatement qualities of the apparatus also allow it to replace the existing muffler or silencer for an engine.

20 Other features and advantages of the present invention should become apparent from the following detailed description of the invention, taken with the included figures and schematics, which illustrate the principles of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

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FIG. 1 is an end view of an embodiment of an apparatus in accordance with the invention for treating lean-burn emissions, with arrows indicating the direction of flow through spiral-shaped inlet and outlet flow passages, with a lean-NOx catalyst, diesel particulate filter, and diesel oxidation catalyst located at the interface between the
30 passages. The embodiment also includes a fuel injector for hydrocarbon addition, as

well as engine speed, pressure and temperature sensors used in optimizing operating performance.

FIG. 2 is a flow diagram that shows the relative positions of the individual components within the apparatus of FIG. 1, and fluid stream flow through the apparatus.

FIG. 3 is a graph depicting the temperature rise of a catalyzed diesel particulate filter and/or a diesel oxidation catalyst in an apparatus that lacks a heat exchanger for heat recovery, and an apparatus with a heat exchanger that is 66% effective.

FIG. 4 is a graph of the temperature rise through the apparatus of FIG. 1, including heat input from reduction of NO_x and oxidation of particulate matter and carbon monoxide.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

With reference now to the illustrative drawings, and particularly to FIG. 1, there is shown an apparatus 10 for treating fluid streams, such as emissions from lean-burn engines, for hydrocarbon (HC), particulate matter (PM), carbon monoxide (CO) and nitrogen oxides (NO_x) in an integrated system. The apparatus can be positioned downstream of a turbocharger in the exhaust duct of an engine or other emissions source.

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The outer surface of the apparatus forms a heat exchanger shell 12. Within the shell are two exchanger walls 14 and 16 that form an inlet passage 18 and an outlet passage 20 for heat exchange between the entering and exiting fluid stream. The exchanger walls allow heat transfer across their surfaces, and can receive normal lean-burn exhaust flows without excess corrosion. The exchanger walls form a spiral

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structure, in which heat exchanges between the pre- and post-treatment streams in an inward spiral flow path and an outward spiral flow path. The exchanger walls are of thin gauge, between 0.018" and 0.040", and are made of muffler grade stainless steel to handle the medium exhaust temperature. Arrows shown in the passages in FIG. 1 indicate the direction of the flow of the fluid stream through the passages. Although a spiral configuration for the exchanger walls is a feature of the preferred embodiment, other known configurations for heat exchange, such as shell-and-tube, plate-and-frame, rotating bed, or flow switching, also are possible.

At the distal ends of the inlet passage 18 and outlet passage 20 are an inlet plenum 26 and an outlet plenum 28, through which the fluid stream enters and exits. The inlet and outlet plenums are configured and designed to produce negligible pressure drop.

A catalyzed diesel particulate filter (DPF) 22 is located in a region at the interface of the inlet passage 18 and outlet passage 20. In the DPF, the fluid stream contacts a filter for PM capture and a catalyst to oxidize PM, HC and CO. The DPF extends across the interface of the inlet and outlet passages, so that the fluid stream flowing from the inlet passage to the outlet passage must pass through the DPF. The DPF can employ platinum- or palladium-treated wall-flow filters as catalyst. The DPF is comprised of silicon carbide, cordierite, metal, or other similar filter material. Preferably, the DPF is a platinum-coated catalyst on a cordierite wall-flow particulate filter. The DPF also can be coated with a non-precious metal ceramic oxide. However, other configurations are possible, such as ceramic foams of small pore size, sintered metal foams, structures composed of ceramic fiber yarn, and any other materials that provide filtering properties.

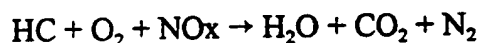
A diesel oxidation catalyst (DOC) 36 is located adjacent to the DPF 22. The DOC is an oxidation catalyst comprised of either precious or non-precious metal on a washcoat, which coats a traditional catalyst substrate. The DOC preferably has a

monolithic structure, but also can be comprised of ceramic or metal foam. Suitable oxidation catalyst materials include platinum, palladium, or any of a family of non-precious metal-based ceramic oxides, such as Mn-O. If the DPF contains sufficient catalyst to perform necessary oxidation, the DOC can be eliminated.

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A lean-NO_x catalyst (LNC) 24 is located upstream of the DPF 22 and DOC 36. The LNC alternatively can be located further upstream, in the inlet passage 18, depending on the preferred operating temperature of the LNC selected. The LNC uses HC as an agent for reducing NO_x via the following global reaction:

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The LNC must be placed such that sufficient HC is available in the stream for the lean-NO_x reaction. This may require that the LNC be placed upstream of a DPF and/or DOC. The LNC preferably is based on alumina and configured to operate between 200°C and 600°C, and therefore is placed accordingly in the correct temperature window of the inlet passage. The LNC alternatively can be based on one of many other formulations known and used in the art. LNC formulations can include, but are not limited to, zeolite and alumina (Al₂O₃) base containing any of a number of transition state metals, such as Al₂O₃, Sn/γ-Al₂O₃, Co-ZSM-5, Cu-ZrO₂, Co/Al₂O₃, Cu-ZSM-5, and Ga-ZSM-5. Use of alumina in and of itself can act as a catalyst for the reduction of NO_x. The appropriate operating temperature range of the LNC is strongly dependent on its composition, from about 200°C up to about 600°C. For example, Pt-Al₂O₃ is most active in the range of 175°C-400°C, while Cu-ZSM-5 is most active in the range of 375°C-450°C, and γ-Al₂O₃ is most active in the range of 450°C-600°C.

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The LNC 24 preferably has a monolithic structure. However, pellets of different shapes, ceramic foams, and metal foams are other possible structures for the LNC. The LNC can use either a ceramic or metal monolithic substrate, with cell density and wall thickness optimized to achieve the highest destruction rates and the

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lowest pressure drops for a specific application. Both metal and ceramic substrates are commercially available in numerous cell densities and wall thicknesses. In alternative embodiments, the LNC is deposited upstream of the DPF 22, along the exchanger walls 14 and 16 in the inlet passage 18. Alternatively, the LNC can be made integral to the DPF by coating the DPF itself with the LNC on the end of the DPF facing the inlet passage.

Another embodiment of the invention includes a DPF 22 and DOC 36 with no LNC 24. In this embodiment, the apparatus 10 serves as a particulate filter or trap. The advantage of this embodiment is the ability to maintain a higher temperature within the core of the apparatus, because there is no need to operate at the lower temperatures required by the LNC. This higher temperature enhances the chemical conversion rates across the DPF and DOC.

Another embodiment of the invention includes a DOC 36 and a LNC 24 with no DPF 22. This embodiment retains the advantage of being able to place the DOC and LNC adjacent to each other because of their similar operating temperatures. This embodiment can be effectively used when the fluid stream to be treated contains a low level of PM.

The preferred embodiment of the invention also includes a fuel injector 32, shown in FIG. 1, to provide additional heat energy to the fluid stream entering the DPF 22, as well as supplementary HC for reaction with NO_x from the fluid stream at the LNC 24. Analysis has shown that the amount of HC required as a reducing agent for the LNC is comparable to the amount required to elevate the DPF to its proper operating temperature. If the stream is an engine exhaust, the fuel injector is placed upstream of the inlet plenum 26 to ensure proper mixing of HC into the stream, and it is cycled for safety and reliability using a pulse-width modulation technique. The fuel injector is used to maintain the operating temperature of the combined catalyst system

in the proper operating range, and to provide for periodic regeneration of the DPF, as discussed below.

In this embodiment, the apparatus 10 also contains various pressure, engine speed (if the stream is an engine exhaust) and temperature sensors to regulate the injection of fuel. Alternative embodiments of the apparatus lack a fuel injector, if such HC injection is not required for the service in which the apparatus operates (i.e., if the temperature is sufficiently high for proper catalyst operation, or if sufficient HC is present in the exhaust stream for LNC 24 reaction). Additionally, an electrical resistance heater 30 may be placed between the inlet passage 18 and the DPF 22, to provide additional heat for optimum operation of the DPF.

The synergism between the different components optimizes the individual performance of the three technologies, providing superior emissions reduction results. The unique configuration of a NOx reduction function, an oxidation function, and a heat recovery function offers several synergistic advantages. First, the LNC 24 used to reduce NOx requires the presence of additional hydrocarbon in the system. Typically, excess HC must be added to achieve maximum NOx reduction. By placing an oxidation catalyst or a catalyzed DPF 22 downstream of the LNC, unreacted HC is oxidized, eliminating emission of HC and CO, and producing heat. This heat raises the temperature of the DPF, facilitating regeneration by oxidizing the carbonaceous PM trapped in the filter. The heat generated by the exothermic oxidation of HC, CO, and PM is recycled by the heat exchanger, thereby preheating the cooler engine exhaust stream entering the system. The recycling of heat facilitates both the reduction of NOx with the LNC and the regeneration of the DPF by increasing the temperatures of these components and the exhaust gases flowing over them.

Finally, the active fuel injection and control system allows further optimization of the system. A number of control strategies can be invoked, depending on the desired performance. For maximum NOx reduction, fuel should be injected

continuously, to maintain an optimum temperature and to supply HC as a reductant to the LNC 24. Alternatively, fuel consumption can be substantially reduced if the fuel is injected only periodically to elevate the DPF 22 temperature for regeneration. A further important function of the fuel injection system is the ability to periodically add sufficient fuel to raise the catalyst temperature above 600°C, or so that all the excess oxygen in the exhaust is consumed. This periodic high temperature/rich cycling can partially reverse sulfur poisoning of the catalysts on the LNC and DPF.

As Table 1 indicates, a ZSM-5 based LNC 24 and a catalyzed DPF 22 will both operate well within the temperature range of 375°C to 450°C, and can therefore be combined in proximity to achieve simultaneous CO, HC, NO_x, and PM reduction. The preferred selection of the LNC and DPF formulations is dependent upon engine size and duty cycle, and upon the sulfur content of the fuel. For a small, light duty engine using low-sulfur fuel, the preferred selections are a Pt- γ -Al₂O₃ LNC, and a Pt-impregnated cordierite DPF. For heavy duty engines (i.e., 12-liter displacement, heavy-duty cycle), the preferred selections are a γ -Al₂O₃ LNC (i.e., with no precious metal), and a Pt-impregnated DPF. The DPF, DOC 36 and LNC are placed serially adjacent between the inlet passage 18 and outlet passage 20, making it easy to keep all of the catalysts operating at their optimum temperatures.

Table 1

<u>PM Oxidation Temperatures</u>	<u>LNC Preferred Temperatures</u>
Without catalyst: 550°C - 600°C	Al ₂ O ₃ based: 450°C - 600°C
With catalyst: 375°C - 450°C	ZSM-5 based: 375°C - 450°C
With fuel addition: 275°C - 350°C	Pt-based low-temp: 175°C - 400°C

FIG. 2 is a flow diagram illustrating operation of the apparatus to treat engine exhaust. On start-up of the engine, and once the catalyst has warmed up to its light-off temperature (approximately 200°C), supplemental HC is introduced through the fuel injector 32 into the exhaust stream. The supplemental HC is reacted

exothermically at the DPF 22 in order to bring the apparatus 10 to the proper operating temperature. After initial start-up, heat from the treated gas in the outlet passage 20 provides most of the added heat necessary to bring the engine exhaust gases to the proper temperature. This is because the exothermic nature of the emissions-reducing reactions across the DPF 22 within the apparatus produce enough heat to ensure the proper preheating of the engine exhaust gases, with minimal input of supplemental HC. The amount of energy required to elevate the exhaust temperature to the appropriate range is significantly reduced, because of the heat recovery afforded by heat exchange between the inner and outer passages.

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Once the stream has been pre-heated sufficiently, reaction begins at the LNC 24, where the NO_x reacts with HC that has been introduced into the stream via the fuel injector 32. Analysis shows that the amount of HC required as a reducing agent for the LNC is comparable to the amount of HC required to bring the DPF 22 to its proper operating temperature. This elevation is preferably accomplished with the fuel injector, by using a pulse-width modulation technique whereby different amounts of HC are introduced upstream of the apparatus, based on a control algorithm that maintains the LNC and DPF at their proper temperature setpoints. This will increase the temperature at the DPF past the light-off temperature, thereby causing PM to be oxidized and the DPF to be regenerated. After passing through the DPF, the treated stream passes through the outlet passage 20 to the outlet plenum 28. This fuel injection can be continuous or intermittent, depending upon the composition of the exhaust stream and the resulting rate of accumulation of PM.

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Because of the relatively low operating temperature of lean-burn engines, the DPF 22 needs to enhance low-temperature PM removal in this service, to avoid plugging under operating conditions of extended idle. To prevent pressure drop due to plugging from becoming excessive, the DPF must be regenerated by heat released by catalytic oxidation. Because the dry carbon particles of the PM require a temperature of at least 400°C to 450°C for ignition, additional heat energy may be required in the

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form of fuel from the fuel injector 32 or electricity from the heating element 30 to bring the DPF up to the appropriate temperature for PM destruction should HC in the entering emission stream be insufficient. To do this, pressure sensors 34 measure pressure drop across the DPF, producing a pressure signal that is input into a controller. If this pressure drop becomes excessive, the controller controls the fuel injector 32 to provide increased HC to raise the temperature to the ignition temperature of the PM. Once pressure drop has fallen to acceptable levels, the controller ends additional HC injection. Also, a temperature sensor 38 measures temperature near the DPF, producing a temperature signal that is input into the controller. If the temperature falls below the optimum operating temperature of the DPF, the controller controls the fuel injector to provide increased HC to elevate the temperature near the DPF.

Engines are tested at different load points to facilitate performance characterization. An example of a load point is 1200 rpm and 500 ft-lbs of torque. Engine idle is the most energy-efficient load point for regeneration of the DPF 22, because less exhaust gas needs to be heated to the light-off temperature. However, temperatures are too low at idle to begin regeneration, and heat released during regeneration (40°C to 100°C) is not great enough to sustain the reaction chemistry.

The temperature rise across a regenerated DPF 22 is up to 40°C. Heat exchange between the inlet passage 18 and outlet passage 20 leverages this temperature rise. FIGS. 3 and 4 illustrate the effect of this heat recovery. FIG. 3 shows the temperature profile of an apparatus comprising a DPF and/or DOC 36, but lacking a heat exchanger, and also shows the temperature profile of an apparatus with DPF and/or DOC and a heat exchanger with 66% efficiency. FIG. 4 shows the temperature profile of an apparatus with a DPF and/or DOC and LNC, as well as a heat exchanger. The figures illustrate the increase in temperature in the fluid stream due to heat exchange between the inlet and outlet passage.

A higher system temperature leads to energy efficient, well-controlled filter regeneration. However, temperatures are too low at idle to begin regeneration, and heat released during regeneration is insufficient to sustain the reaction chemistry. During operation, flow passes through the inlet plenum 26 into the inlet passage 18. In the inlet passage, the fluid stream is heated by thermal exchange with the hotter gas in the outlet passage 20. The heat exchange between the inlet and outlet passages increases the temperature of the fluid stream beyond the rise from the heat released by the catalyzed reactions, to the optimum temperatures at which the catalyst in the DPF 22 and the LNC 24 operate. This heat exchange leverages the temperature rise, as shown in Table 2. The effectiveness of a heat exchanger is defined as:

$$(\eta(\%) = 1 - (\Delta T_{\text{reaction}} / \Delta T_{\text{system}}).$$

Table 2

Heat Exchanger Effectiveness, η (%)	$\Delta T_{\text{reaction}}$	ΔT_{system}
0	40	40
50	40	80
66	40	120
80	40	200
90	40	400

If used to treat engine exhaust streams, the apparatus 10 is configured to have a catalyst volume from half to three times the displacement of the engine; i.e., a 12-liter engine will require a 6-liter to 36-liter volume to contain its LNC 24, DPF 22 and DOC 38.

Although the invention has been disclosed in detail with reference only to the preferred embodiments, those skilled in the art will appreciate that alternative embodiments of the apparatus can be constructed without departing from the scope of the invention. Accordingly, the invention is defined only by the following claims.

We claim:

1. Apparatus for processing a fluid stream, comprising:
a heat exchanger having first and second spaced-apart walls that define an inlet passage and an outlet passage for the fluid stream, wherein the walls are configured to transfer heat from the outlet passage to the inlet passage; and
5 a diesel particulate filter integrally connected to the heat exchanger and positioned to transmit the fluid stream from the inlet passage to the outlet passage, wherein the diesel particulate filter is configured to oxidize carbon monoxide and hydrocarbons, and to collect and oxidize particulate matter present in the fluid stream.
2. The apparatus of claim 1, wherein the diesel particulate filter is a ceramic wall-flow particulate filter.
3. The apparatus of claim 1, wherein the diesel particulate filter comprises a material selected from the group consisting of ceramic foam, sintered metal foam, and ceramic fiber yarn.
4. The apparatus of claim 1, wherein the diesel particulate filter comprises a catalyst.
5. The apparatus of claim 4, wherein the catalyst comprises a material selected from the group of platinum, palladium, and ceramic oxide.
6. The apparatus of claim 1, and further comprising a lean-NOx catalyst located upstream of the diesel particulate filter, wherein the lean-NOx catalyst is configured to reduce nitrogen oxides present in the fluid stream.
7. The apparatus of claim 6, wherein the lean-NOx catalyst is located immediately adjacent to the diesel particulate filter.

8. The apparatus of claim 7, wherein:
the diesel particulate filter has a surface facing the inlet passage; and
wherein the lean-NOx catalyst is deposited on the surface of the diesel particulate filter facing the inlet passage.
9. The apparatus of claim 6, wherein the lean-NOx catalyst has a monolithic structure.
10. The apparatus of claim 6, wherein the lean-NOx catalyst is comprised of a material selected from the group consisting of precious metal, ceramic foam, and metal foam.
11. The apparatus of claim 1, and further comprising a diesel oxidation catalyst integrally connected to the heat exchanger, between the inlet and outlet passage, wherein the diesel oxidation catalyst is configured to oxidize carbon monoxide and hydrocarbons present in the fluid stream.
12. The apparatus of claim 10, wherein the diesel oxidation catalyst comprises metal.
13. The apparatus of claim 10, wherein the diesel oxidation catalyst comprises ceramic foam or metal foam.
14. The apparatus of claim 1, and further comprising a fuel injector located and configured to inject hydrocarbons into the inlet passage.
15. The apparatus of claim 14, and further comprising:
one or more pressure sensors configured to produce a pressure signal indicative of any pressure drop through the diesel particulate filter;

- 5 a temperature sensor configured to produce a temperature signal,
indicative of the temperature at a predetermined position adjacent to the diesel
particulate filter; and
a controller, responsive to the pressure signal and the temperature signal,
for controlling the rate at which the fuel injector injects hydrocarbons into the inlet
passage.

16. The apparatus of claim 15, wherein the controller is selected to
maintain the pressure drop through the diesel particulate filter at or below a specified
level.

17. The apparatus of claim 15, wherein the controller is selected to
maintain the temperature at a predetermined position adjacent to the diesel particulate
filter at or below a specified level.

18. The apparatus of claim 15, wherein:
the fluid stream is the exhaust from an engine;
the engine comprises an engine speed sensor configured to produce an
engine speed signal indicative of the engine's speed; and
5 the controller is responsive to the engine speed signal for controlling the
rate at which the fuel injector injects hydrocarbons into the inlet passage.

19. The apparatus of claim 1, and further comprising a resistance heater
configured to heat the fluid stream in the inlet passage.

20. The apparatus of claim 1, wherein the first and second spaced-apart
walls have a spiral configuration.

21. Apparatus for processing a fluid stream, comprising:
a heat exchanger having first and second spaced-apart walls that define an inlet passage and an outlet passage for the fluid stream, wherein the walls are configured to transfer heat from the outlet passage to the inlet passage; and
5 a diesel oxidation catalyst integrally connected to the heat exchanger, between the inlet and outlet passage, wherein the diesel oxidation catalyst is configured to oxidize carbon monoxide and hydrocarbons in the fluid stream; and
a lean-NOx catalyst located upstream of the diesel oxidation catalyst, wherein the lean-NOx catalyst is configured to reduce nitrogen oxides in the stream.
22. The apparatus of claim 21, wherein the diesel oxidation catalyst comprises metal.
23. The apparatus of claim 21, wherein the diesel oxidation catalyst comprises ceramic foam or metal foam.
24. The apparatus of claim 21, wherein the lean-NOx catalyst is located immediately adjacent to the diesel oxidation catalyst.
25. The apparatus of claim 24, wherein:
the diesel oxidation catalyst has a surface facing the inlet passage; and
wherein the lean-NOx catalyst is deposited on the surface of the diesel oxidation catalyst facing the inlet passage.
26. The apparatus of claim 21, wherein the lean-NOx catalyst has a monolithic structure.
27. The apparatus of claim 21, wherein the lean-NOx catalyst is comprised of a material selected from the group consisting of precious metal, ceramic foam, and metal foam.

28. The apparatus of claim 21, and further comprising a fuel injector located and configured to inject hydrocarbons into the inlet passage.

29. The apparatus of claim 28 and further comprising:
a temperature sensor configured to produce a temperature signal, indicative of the temperature at a predetermined position adjacent to the diesel oxidation catalyst and
5 a controller, responsive to the temperature signal, for controlling the rate at which the fuel injector injects hydrocarbons into the inlet passage.

30. The apparatus of claim 29, wherein the controller is selected to maintain the temperature at a predetermined position adjacent to the diesel oxidation catalyst at or below a specified level.

31. The apparatus of claim 29, wherein:
the fluid stream is the exhaust from an engine;
the engine comprises an engine speed sensor configured to produce an engine speed signal indicative of the engine's speed; and
5 the controller is responsive to the engine speed signal for controlling the rate at which the fuel injector injects hydrocarbons into the inlet passage.

32. The apparatus of claim 21, and further comprising a resistance heater configured to heat the fluid stream in the inlet passage.

33. The apparatus of claim 21, wherein the first and second spaced-apart walls have a spiral configuration.

34. Apparatus for processing a fluid stream, comprising:
- a heat exchanger having first and second spaced-apart walls that define an inlet passage and an outlet passage for the fluid stream, wherein the walls are configured to transfer heat from the outlet passage to the inlet passage;
 - 5 a diesel particulate filter integrally connected to the heat exchanger and positioned to transmit the fluid stream from the inlet passage to the outlet passage, wherein the diesel particulate filter is configured to oxidize carbon monoxide and hydrocarbons, and to collect and oxidize particulate matter present in the fluid stream;
 - a diesel oxidation catalyst integrally connected to the heat exchanger,
10 between the inlet and outlet passage, wherein the diesel oxidation catalyst is configured to oxidize carbon monoxide and hydrocarbons present in the fluid stream;
 - a lean-NO_x catalyst located upstream of the diesel particulate filter, wherein the lean-NO_x catalyst is configured to reduce nitrogen oxides present in the fluid stream;
 - 15 a fuel injector located and configured to inject hydrocarbons into the inlet passage;
 - one or more pressure sensors configured to produce a pressure signal indicative of any pressure drop through the diesel particulate filter;
 - a temperature sensor configured to produce a temperature signal,
20 indicative of the temperature at a predetermined position adjacent to the diesel particulate filter;
 - a controller, responsive to the pressure signal and the temperature signal, for controlling the rate at which the fuel injector injects hydrocarbons into the inlet passage;
 - 25 wherein the controller is selected to maintain the pressure drop through the diesel particulate filter at or below a specified level, and to maintain the temperature at a predetermined position within the diesel particulate filter at or below a specified level; and
 - a resistance heater configured to heat the fluid stream in the inlet passage.

35. The apparatus of claim 34, wherein:
the fluid stream is the exhaust from an engine;
the engine comprises an engine speed sensor configured to produce an engine speed signal indicative of the engine's speed; and
5 the controller is responsive to the engine speed signal for controlling the rate at which the fuel injector injects hydrocarbons into the inlet passage.
36. A method for processing a fluid stream, comprising:
preheating the fluid stream by heat exchange using an exiting treated fluid stream; and
oxidizing carbon monoxide and hydrocarbons, and collecting and
5 oxidizing particulate matter in the preheated fluid stream, to produce the exiting treated fluid stream.
37. The method of claim 36, wherein oxidizing carbon monoxide and hydrocarbons, and collecting and oxidizing particulate matter present in the preheated fluid stream is performed using a diesel particulate filter.
38. The method of claim 36, wherein oxidizing carbon monoxide and hydrocarbons present in the preheated fluid stream is performed using a diesel oxidation catalyst.
39. The method of claim 36, and further comprising reducing nitrogen oxides present in the preheated fluid stream.
40. The method of claim 39, wherein reducing nitrogen oxides present in the preheated fluid stream is performed using a lean-NO_x catalyst.
41. The method of claim 36, and further comprising injecting hydrocarbon into the preheated fluid stream.

42. The method of claim 41, wherein injecting hydrocarbon into the preheated fluid stream comprises:
measuring the temperature at a point in the preheated fluid stream; and
controlling the rate at which hydrocarbon is injected into the preheated
5 fluid stream based upon the measured temperature.

43. The method of claim 41, wherein injecting hydrocarbon into the preheated fluid stream comprises:
measuring the pressure at points in the preheated fluid stream; and
controlling the rate at which hydrocarbon is injected into the preheated
5 fluid stream based upon the measured pressures.

44. The method of claim 41, wherein the preheated fluid stream is the exhaust from an engine, and further comprising:
measuring the speed of the engine; and
controlling the rate at which hydrocarbon is injected into the preheated
5 fluid stream based upon the measured engine speed.

45. The method of claim 36, and further comprising preheating the fluid stream using an external heat source prior to preheating using the exiting treated fluid stream.

46. A method for processing a fluid stream, comprising:
preheating the fluid stream by heat exchange using an exiting treated fluid
stream; and
oxidizing carbon monoxide and hydrocarbons, and reducing nitrogen
5 oxides present in the preheated fluid stream, to produce the exiting treated fluid stream.

47. The method of claim 46, wherein oxidizing carbon monoxide and hydrocarbons present in the preheated fluid stream is performed using a diesel oxidation catalyst.

48. The method of claim 46, wherein reducing nitrogen oxides present in the preheated fluid stream is performed using a lean-NOx catalyst.

49. The method of claim 46, and further comprising injecting hydrocarbon into the preheated fluid stream.

50. The method of claim 49, wherein injecting hydrocarbon into the preheated fluid stream comprises:

measuring the temperature at a point in the preheated fluid stream; and
controlling the rate at which hydrocarbon is injected into the preheated
5 fluid stream based upon the measured temperature.

51. The method of claim 49, wherein the preheated fluid stream is the exhaust from an engine, and further comprising:

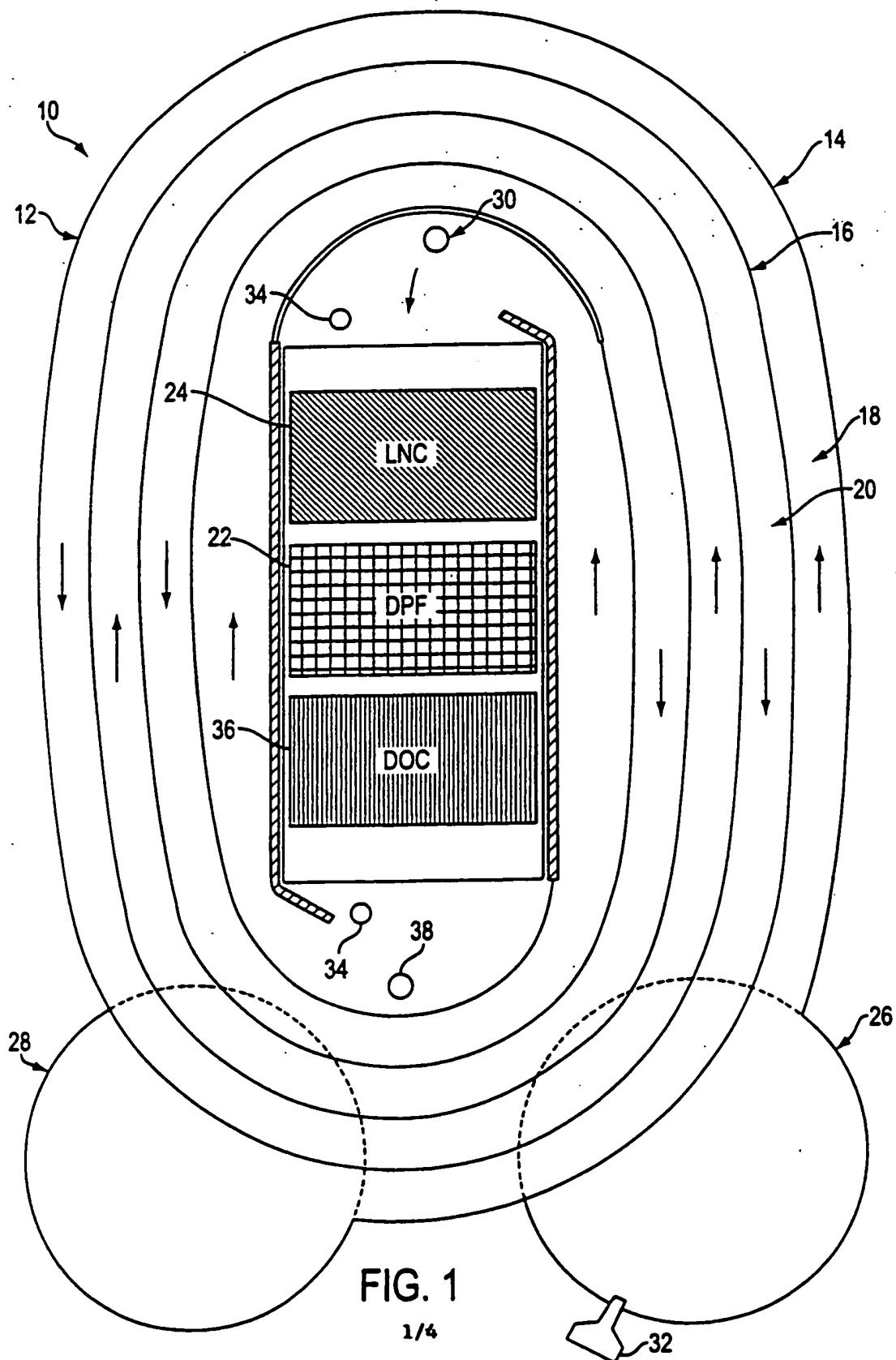
measuring the speed of the engine; and
controlling the rate at which hydrocarbon is injected into the preheated
5 fluid stream based upon the measured engine speed.

52. The method of claim 46, and further comprising preheating the fluid stream using an external heat source prior to preheating using the exiting treated fluid stream.

53. A method for processing a fluid stream, comprising:
preheating the fluid stream using an external heat source;
further preheating the fluid stream by heat exchange using an exiting
treated fluid stream;

- 5 measuring the temperature at a point in the preheated fluid stream;
 measuring the pressure at points in the preheated fluid stream;
 injecting hydrocarbon into the preheated fluid stream;
 controlling the rate at which hydrocarbon is injected into the preheated
fuel stream based upon the measured temperature and pressures;
10 reducing nitrogen oxides in the preheated fluid stream; and
 oxidizing carbon monoxide and hydrocarbons, and collecting and
oxidizing particulate matter in the preheated fluid stream to produce the exiting treated
fluid stream.

54. The method of claim 53, wherein the preheated fluid stream is the exhaust from an engine, and further comprising measuring the speed of the engine and controlling the rate at which hydrocarbon is injected into the preheated fuel stream based upon the measured engine speed.

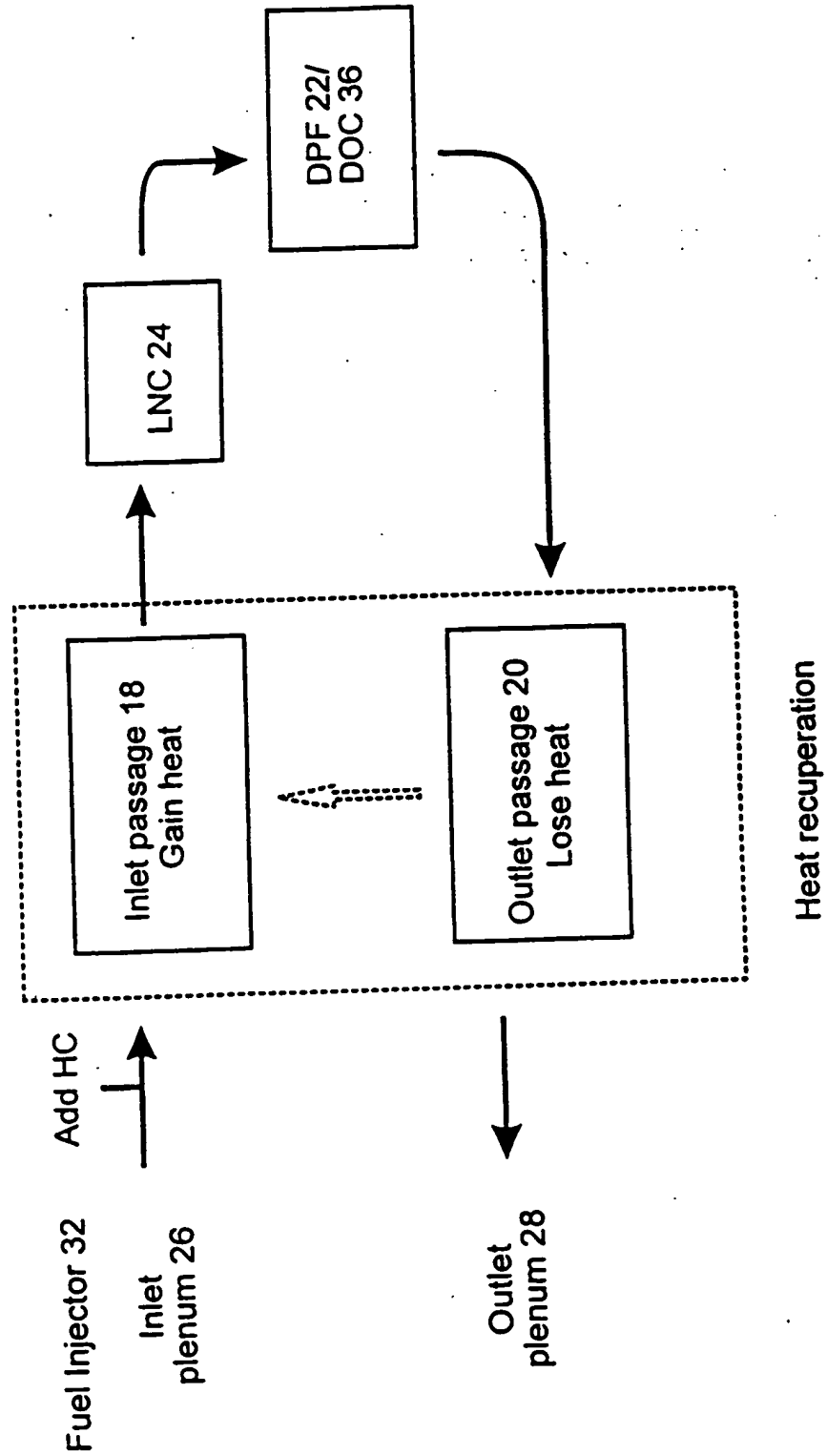


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FIG. 2

Fluid Flow Path

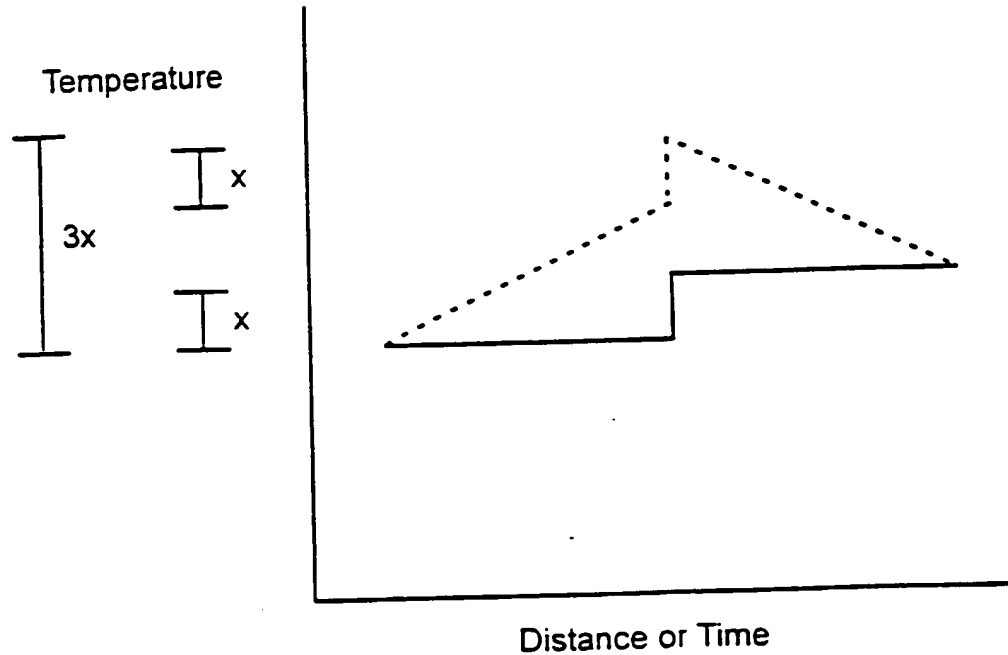


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FIG. 3

Temperature Profiles Through Apparatus
With and Without Heat Recovery



--- Heat recovery (66% effective)

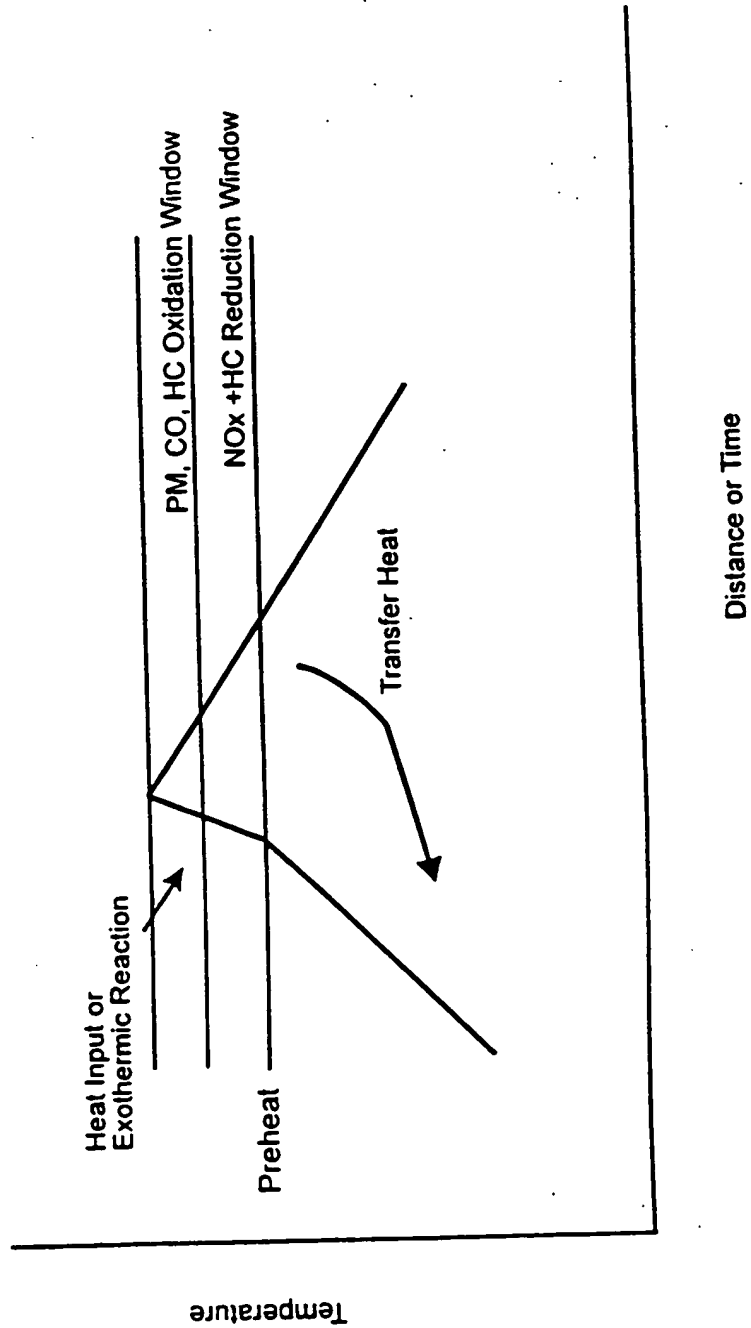
— No heat recovery

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FIG. 4

Temperature Profile Through Reaction Windows



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and Application No
PCT/US 99/26050

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 F01N3/28 F01N3/20 F01N3/035 B01D53/94

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 F01N B01D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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A	—	21,34,53
X	US 5 326 537 A (CLEARY JAMES M) 5 July 1994 (1994-07-05) column 1, line 5 -column 2, line 31 column 7, line 37 -column 9, line 30; figure 4	36,46
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	— -/-	

☒ Further documents are listed in the continuation of box C.

☒ Patient family members are listed in annex.

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Date of the actual completion of the international search

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INTERNATIONAL SEARCH REPORT

International Application No
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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
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